EXPLORESPACE TECH
TECHNOLOGY DRIVES EXPLORATION

EXPLORE: Advanced Manufacturing
NASA Space Technology Mission Directorate
August 2022

STMD welcomes feedback on this presentation
See [80HQTR22ZOA2L_EXP_LND] at [nspires.nasaprs.com] for how to provide feedback
If there are any questions, contact [HQ-STMD-STAR-RFI@nasaprs.com]

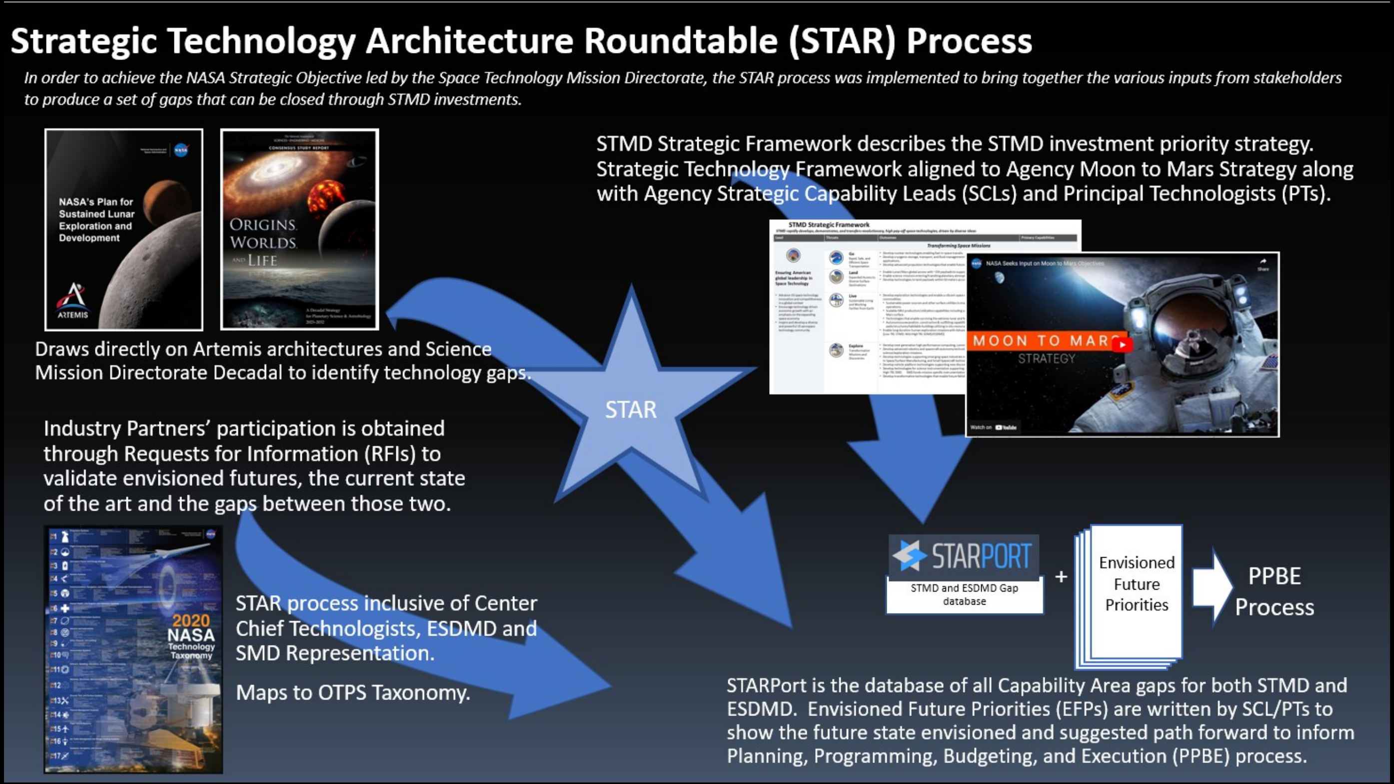
How We Explore… NASA Manufacturing

Inclusive Strategic Technology Planning

STMD utilizes STAR, the Strategic Technology Architecture Roundtable, to collect a diverse set of inputs into the strategic technology planning process.

- Draws directly on Artemis/ISS needs and SMD Science Decadal Studies: all NASA Center Chief Technologists and Mission Directorates included.
- Regular inputs directly from industry-on-industry plans and needs.
- Secure coordination and collaboration with US Space Force and DoD entities.

https://techport.nasa.gov/framework



Strategic Technology Framework

STMD rapidly develops, demonstrates, and transfers revolutionary, high pay-off space technologies, driven by diverse ideas

Lead	Thrusts	Outcomes	Primary Capabilities
Ensuring American global leadership in Space Technology • Advance US space technology innovation and competitiveness in a global context • Encourage technology driven economic growth with an emphasis on the expanding space economy • Inspire and develop a diverse and powerful US aerospace technology community	**Go** Rapid, Safe, and Efficient Space Transportation	• Develop nuclear technologies enabling fast in-space transits. • Develop cryogenic storage, transport, and fluid management technologies for surface and in-space applications. • Develop advanced propulsion technologies that enable future science/exploration missions.	• Nuclear Systems* • Cryogenic Fluid Management* • Advanced Propulsion*
	Land Expanded Access to Diverse Surface Destinations	• Enable Lunar/Mars global access with ~20t payloads to support human missions. • Enable science missions entering/transiting planetary atmospheres and landing on planetary bodies. • Develop technologies to land payloads within 50 meters accuracy and avoid landing hazards.	• Entry, Descent, Landing, & Precision Landing*

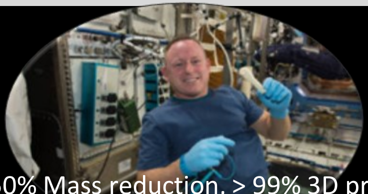
	Live
	Sustainable Living and Working Farther from Earth
		• Develop exploration technologies and enable a vibrant space economy with supporting utilities and commodities
		  ◦ Sustainable power sources and other surface utilities to enable continuous lunar and Mars surface operations.
		  ◦ Scalable ISRU production/utilization capabilities including sustainable commodities on the lunar & Mars surface.
		  ◦ Technologies that enable surviving the extreme lunar and Mars environments.
		  ◦ Autonomous excavation, construction & outfitting capabilities targeting landing pads/structures/habitable buildings utilizing in situ resources.
		• Enable long duration human exploration missions with Advanced Habitation System technologies. [Low TRL STMD; Mid-High TRL SOMD/ESDMD]
			• Advanced Power*
			• In-Situ Resource Utilization*
			• Advanced Thermal*
			• Advanced Materials, Structures, & Construction*
			• Advanced Habitation Systems*

* represents contributing crosscutting technologies	**Explore** Transformative Missions and Discoveries	• Develop next generation high performance computing, communications, and navigation. • Develop advanced robotics and spacecraft autonomy technologies to enable and augment science/exploration missions. • Develop technologies supporting emerging space industries including: Satellite Servicing & Assembly, In Space/Surface Manufacturing, and Small Spacecraft technologies. • Develop vehicle platform technologies supporting new discoveries. • Develop technologies for science instrumentation supporting new discoveries. [Low TRL STMD/Mid-High TRL SMD. SMD funds mission specific instrumentation (TRL 1-9)] • Develop transformative technologies that enable future NASA or commercial missions and discoveries	• Advanced Avionics Systems • Advanced Communications & Navigation • Advanced Robotics • Autonomous Systems • Satellite Servicing & Assembly* • Advanced Manufacturing • Small Spacecraft* • Rendezvous, Proximity Operations & Capture • Sensor & Instrumentation

EXPLORE: Develop technologies supporting emerging space industries

Priorities - Targeted advanced manufacturing outcomes aligned with space industry trends that will shape the course of research and development over many years

In-Space Manufacturing and Space Infrastructure



> 50% Mass reduction, > 99% 3D printer readiness. A catalyst for space infrastructure and economic opportunities

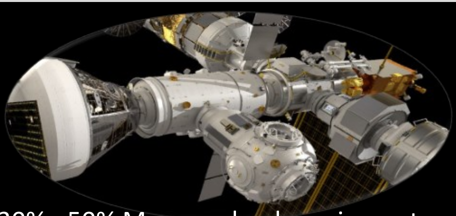
3D Printing/Additive Manufacturing

> 50% Cost reduction, 12 months instead of five years, Parts reduction >100 to 1

Digital Transformation - Digital Twins and Artificial Intelligence

More intelligent and more accurate predictions and capabilities, > 50% of physical resources replaced with virtual

Lightweight Composites Spacecraft



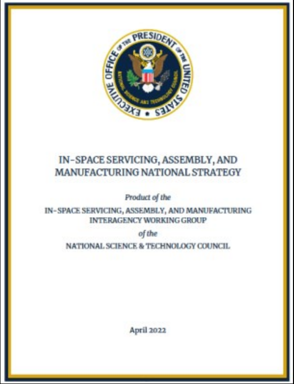
30% - 50% More payload, equipment, and experiments

EXPLORE: Develop technologies supporting emerging space industries

Advanced Manufacturing technologies make NASA's missions more capable and affordable by bringing together industry, academia, and government

Plan to close gaps and achieve outcomes

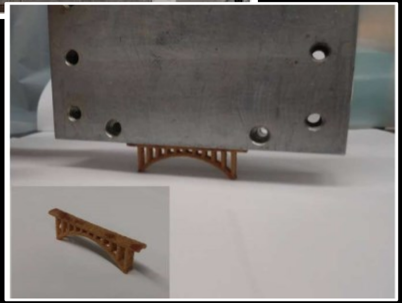
- Integrated plan across Mission Directorates and Centers; Across TRLs (e.g., leverage STRG), programs and projects pipeline; Industry/Academia alignment, Workshops/TIMs
- Increase collaboration and public private partnerships. Leverage National Strategic Plans: Office of Science and Technology Policy Subcommittee on Advanced Manufacturing; In-Space Servicing, Assembly, and Manufacturing; Materials Genome Initiative; National Nanotechnology Initiative; others
- Outcome based - Innovative advanced manufacturing technologies targeted at commercial drivers for performance, affordability, and sustainability. "Bridge the Valley of Death"



In Space Manufacturing and Space Infrastructure

Motivation/State of the Art

- Aligned with Lunar Utilization infrastructure priorities “industrialization of the Moon”
- The Post-ISS Plan: Commercial demand for in-space manufacturing
- The current logistics model is unsustainable for long duration space missions
- 3D Printer GCD tech demo on-board ISS in 2014
- 20 years of ISS microgravity materials science research (SMD BPS)
- STMD GCD ISM project (FabLab prototype testing)
- ISS commercial In Space Production Applications (InSPA)
- ISS National Lab/CASIS In-orbit materials/manufacturing
- NASA OSAM-1 and OSAM-2



Next Steps, Future Focus Areas and Investments

- Announcement of Collaboration Opportunity & Partnership Proposals to Advance Tipping Point Technologies
- On-demand manufacturing of metals, electronic components, recycling and reuse
- ISRU-derived materials for feedstocks (e.g., Al, Si) for lunar surface manufacturing
- Certification is a top challenge - Physics-based models to predict processing and material properties
- ISAM - welding in space, recycling and reuse, large scale additive manufacturing
- Maximize use of ISS for demonstration

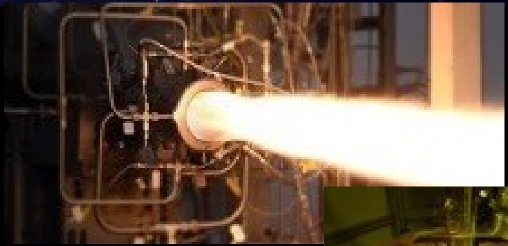
3D Printing/Additive Manufacturing

Motivation/State of the Art

- Administration Launch of AM Forward Initiative
- Revolutionary design flexibility and dramatic reductions in cost/schedule
- Ideal applications for complex components (e.g., liquid rocket engines)
- Large-scale additive technologies are just being demonstrated
- Available materials are limited and not optimized for AM
- All empirical certification approaches
- Variability is the achilles heel

Next Steps, Future Focus Areas and Investments

- Accelerate additive manufacturing certification (computational tools in concert with experimentation)
- Materials for extreme environments (e.g., refractories for nuclear)
- New processes (e.g., additive friction stir, directed energy)
- Large scale freeform applications
- NDE/Inspection, In situ monitoring, and closed-loop control
- Technologies for non-propulsion structures (e.g., common bulkheads, tanks, domes, optical structures etc.)
- Advance modeling and simulation for optimal parameters, property predictions and material designs

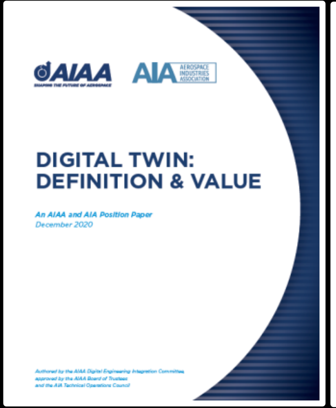


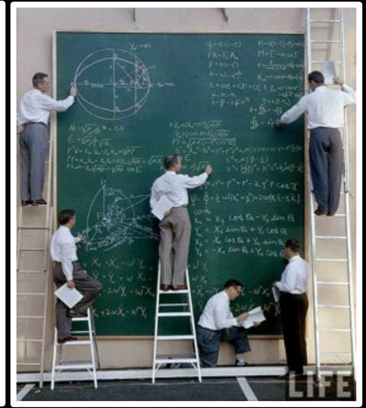
Extensive National Collaborations - Industry Driven Focus

Manufacturing Digital Transformation
Digital Twins and Artificial Intelligence

Motivation/State of the Art

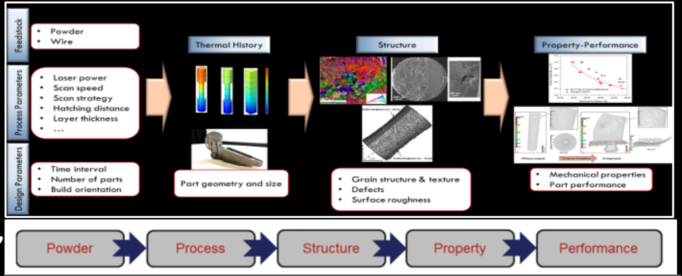
- Complexity of aerospace systems has significantly outpaced conventional development approaches – Inflection point!
- Global competition to achieve economic leadership through the development and application digital transformation
- Industry 4.0 EU strategic initiative for digital transformations in design, manufacture, and operations
- Air Force to develop F-16 "digital twin"
- Limited physics-based computational materials, design and manufacturing capabilities in use today (e.g., ICME, MGI initiatives)





Next Steps, Future Focus Areas and Investments

- Interdisciplinary modeling across the building block levels of "R&D to certification" (major agency/industry problem)
- Digital twin physics-based modeling and simulation of predictive relationships between processing parameters, material microstructure, material properties, and hardware performance
- Artificial intelligence, machine learning, and digital twin technologies for manufacturing processes

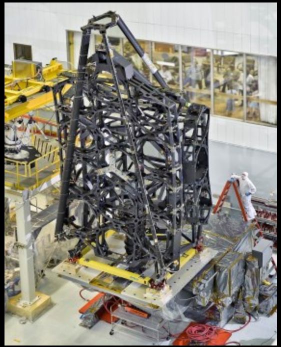


Modeling Process-Structure-Property Relationships for Additive Manufacturing

Lightweight Composite Spacecraft

Motivation/State of the Art

- Decadal Survey (Astro2020) - “Composite Material Process Development and Optimization”
- Immediate 30% weight savings and 25% cost savings compared to SOA
- Aluminum is most widely used in space vehicle structures
- Composites usage in space applications lags aviation and military
- Thermoplastic composites development is rapidly advancing
- Thermoset composites are de facto baseline and mechanical fastening is still primarily used (joints are the achilles heel)



Next Steps, Future Focus Areas and Investments

- Dimensional stability - Topic 3 ECF22
- Early Stage Innovations Solicitation
- Thermoplastic composites for space applications
- Adhesive bonding thermosets and welding thermoplastics
- Tailorable properties offer new design possibilities
- Digital/model-based discovery, characterization, and maturation
- High temperature materials & structures
- New materials and space environmental effects on materials
- Accelerated analytical certification and failure mode approaches

Current Investments

Additive Manufacturing

- On-orbit servicing, assembly, and manufacturing
- Rapid analysis and manufacturing propulsion technology
- Additive manufacturing of thermal protection systems
- Refractory alloys processing by additive manufacturing
- Additively manufacturing for tribological and radiation resistance improvement
- Metal digital direct manufacturing for combustion chambers and nozzles
- Moon to Mars oxygen and steel technology
- Computational design of functionally graded materials
- Design of metastable high entropy alloys for additive manufacturing
- Additive manufacturing for rotating detonation rocket propulsion
- Predicting the integrity of additively manufactured nickel alloys

In-Space Manufacturing

- On-orbit servicing, assembly, and manufacturing
- In-space manufacturing: on-demand manufacturing electronics
- In-space manufacturing: on-demand manufacturing metals
- In-space manufacturing: recycling and reuse
- Commercial feasibility of in-space manufacturing applications
- In-space assembly of perovskite solar cells for very large arrays
- In-space production applications (InSPA) ISS Implementation strategy
- Microgravity materials science program
- Materials International Space Station Experiment
- On-surface 3D printing of sodium-ion batteries using ISRU materials
- In-space coating development utilizing atomic layer deposition

Composites

- Institute for ultra-strong composites by computational design
- Superlightweight aerospace composites
- Deployable composite booms
- RAMPT carbon-carbon nozzle
- Composite technology for exploration
- Thermoplastics development for exploration applications
- 3D printing for low mass, multifunctional polymer composites
- Multifunctional composite textile materials for advanced spacesuits
- Manufacturing variation in multiscale analysis of composite structures
- Advanced composite solar sail
- OOA process or manufacture of large thin gauge composites
- Lightweight radiation shielding composites for small spacecraft
- ARMD hi-rate composite aircraft manufacturing

Manufacturing Digital Transformation

- Multiscale framework for material systems
- Modeling of additive manufacturing processes
- Process simulation for thin-ply composites
- Tool material design for friction stir welding
- Computational design of polymeric materials
- Digital twins for controlled environment plant production in space
- Computational design of graded alloys made with additive manufacturing
- Microstructure and defect informed predictions of damage tolerance
- Computational modeling of residual stresses in additive parts
- Digital twin certification for additive manufacturing
- Multiphysics integrated modeling of self-reading friction stir welding

(*representative project activities, not a comprehensive list)

Summary

- Advanced manufacturing technologies are critical to NASA, the Nation's aerospace industry, and almost every sector of the U.S. economy
- White House Critical Emerging Technology List - Advanced Manufacturing (Additive Manufacturing), Space Technologies and Systems (In-Space servicing, assembly, and manufacturing), Advanced Engineering Materials (Materials Genome), Artificial Intelligence
- Better collaboration between government, industry, and academia will accelerate realization of innovative technologies
- An integrated/focused plan of investment strategies across the full TRL pipeline and across Mission Directorates
  - Linked to Agency missions, other national needs, and commercial strategies
  - Deep understanding of SOA, key challenges, and emerging innovations
  - Bridge the "valley of death" for translational technologies from science to manufacturing

Acronyms

- ARMD: Aeronautics Research Mission Directorate
- BPS: Biological and Physical Sciences
- GCD: Game Changing Development
- ICME: Integrated Computational Materials Engineering
- InSPA: In-Space Production Applications
- ISAM: In-space Servicing, Assembly, and Manufacturing
- ISRU: In-Situ Resource Utilization
- MGI: Materials Genome Initiative
- NASA: National Aeronautics and Space Administration
- OCT: Office of the Chief Technologist
- OOA: Out Of Autoclave
- R&D: Research and Development
- SMD: Science Mission Directorate
- SOA: State of the Art
- STAR: Strategic Technology Architecture Roundtable
- STMD: Space Technology Mission Directorate
- STRG: Space Technology Research Grants
- TIM: Technical Interchange Meeting
- TRL: Technology Readiness Level